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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 :
F24D 19/10, F24H 9/20, G01K 7/08

A1

(11) International Publication Number: WO 00/58668

(43) International Publication Date: 5 October 2000 (05.10.00)

(21) International Application Number: PCT/IL00/00159

(22) International Filing Date: 15 March 2000 (15.03.00)

(30) Priority Data:
129269 30 March 1999 (30.03.99) IL

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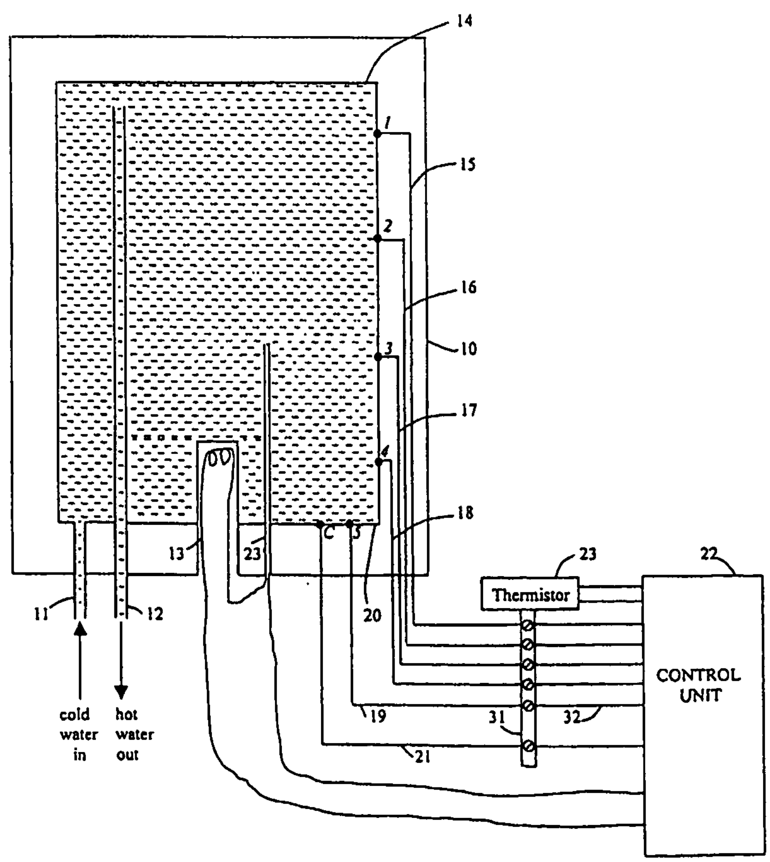
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: HOT WATER TANK

(57) Abstract

A hot water tank and method for estimating an available quantity of usable water having a desired water temperature therein, the tank being fed by cold water heated by a controllable heating element containing an electrically conductive wall, a heating element and at least three temperature sensors disposed at respective heights of the tank for measuring local water temperature at respective points thereof. Each of the temperature sensors is an electrical conductor formed of a material different to that of the electrically conductive wall of the tank and which is bonded to the wall so as to form a thermocouple at a respective point of contact.



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HOT WATER TANK

FIELD OF THE INVENTION

This invention relates to hot water installations and, in particular, to thermostatic control of the water temperature in such devices.

BACKGROUND OF THE INVENTION

Domestic hot water installations typically include a hot water tank which may be situated within a house or apartment or, alternatively, on the roof thereof. In either case, the hot water temperature is normally factory set, provision possibly being made for adjustment thereof during installation. Typically, such adjustment requires specialized knowledge and/or tooling and is beyond the ability of the average house-holder.

In such hot water systems, the water is maintained at the same constant temperature throughout both winter and summer and a person wishing to take a shower mixes hot water from the tank with cold water in order to achieve a comfortable shower temperature, typically between 40°C and 45°C. This is, clearly, an extravagant waste of energy since during the summer, when the ambient air temperature is high, much less hot water is required in the mix than in winter when the ambient temperature is low, since the temperature of the cold water is then correspondingly low and so more hot water is required to raise the average temperature of a desired quantity of shower water to the desired temperature.

In countries wherein the sun can be relied on to shine for most days of the year it is very common to provide hot water either exclusively or, at least in part, by solar heating. A solar panel is provided on the roof of the building and hot water is contained in a storage tank also normally situated on the roof of the building adjacent to the solar panel. Water is fed to the domestic hot water supply system via a thermally insulated pipe running from the storage tank on the roof of the building and gaining entrance to the domestic hot water supply.

Whether the water is heated using solar power or other means, some electrical backup is also normally provided in the form of an electrical immersion heater disposed within the hot water tank. The immersion heater brings the hot water up to temperature relatively quickly, and is often used fairly indiscriminately by a householder who wishes to take a bath or a shower quickly and speculates that the hot water temperature is inadequate. Owing to the fact that the householder has no way either of adjusting or even measuring the actual temperature of the hot water in the storage tank, the decision to boost the hot water temperature by using the electrical immersion heater amounts to guesswork on the part of the householder and, as often as not, will result in unnecessary wastage of energy.

Furthermore, owing to the high cost of electricity, it is obviously desirable to use an electrical immersion heater in order to boost the water temperature only to the extent that is absolutely required. For example, a person who wishes to boost the water temperature prior to taking a shower, clearly has no need to heat the water tank "temperature profile" to the highest temperature enabled by the boiler thermostat. It is sufficient to heat the water tank "temperature profile" such that, when the hot water in the tank is mixed with cold water derived from the cold water supply, the resulting hot water temperature is around 40 to 45°C (the temperature usually most comfortable for a shower) for the desired shower duration. However, since it cannot be predicted in advance how much cold water will be mixed with the hot water in the tank, it is no simple matter to indicate to the householder how much of a water tank's contents are at a sufficiently high

temperature so that the resulting water temperature, after mixing with cold water, is at a desired, pre-set temperature.

Moreover, as is known, domestic water tanks allow for the hot water to be syphoned off at the top of the tank and to be replaced by cold water which is fed in at the bottom of the tank. Notwithstanding the constant hot water drainage and cold water replacement which thus ensues, there exists a marked temperature gradient throughout the tank such that the temperature of water toward the upper part of the tank is greater than that of the water near the base of the tank. Thus, merely placing a temperature probe toward the upper surface of the tank would tend to provide an artificially high reading; whilst placing a temperature probe toward the base of the tank would provide an artificially low reading. In the former case, a householder might be tempted to take a shower under the misguided impression that there is sufficient hot water in the tank, only to find in practice that the water is too cold. In the latter case, the householder would be tempted to heat the water for an unnecessarily long time under the misguided impression that the water temperature has not yet reached a comfortable threshold. Furthermore, the amount of "shower water" depends also on the temperature of "cold" water in the cold water supply cock which itself depends on the surrounding temperature.

U.S. Patent No. 5,556,564 (Wittner) discloses a control unit for controlling the temperature of a domestic water supply, comprising at least two temperature sensors for inserting into a water tank so as to produce respective sensor signals representative of actual water temperature in a region of the temperature sensor and an electrical immersion heater for inserting into the water tank and energized by a source of electrical power. A setting device is adjusted by a user for setting a desired water temperature and producing a corresponding set signal, and a controllable switch is connected between the source of electrical power and the electrical immersion heater, and is responsive to the sensor signals and to the set signal for closing if the actual water temperature is lower than the desired water temperature and for opening if the actual water temperature is greater than the desired water temperature.

The Wittner device is typical of prior art devices which place several temperature sensors at predetermined heights within the hot water tank so that their respective readings give the householder an indication of the local temperature of the water in the vicinity of the sensor. Such affixing of temperature sensors at different heights within the water tank is preferably performed during manufacture of the tank itself. To the extent that they are inserted after the tank is manufactured, this can be done only by boring holes through the wall of the tank, inserting the temperature sensors and then sealing the holes against water leakage in a manner which will withstand the water pressure in the tank. This is clearly an involved procedure which adds to the cost of the tank and may detract from its reliability.

Furthermore, the temperature sensors must be protected against corrosion owing to their direct contact with water. Also, some prior art devices employ several heating elements for heating different spatially distributed volumes of water on the basis that if only a small quantity of water is required, then only the uppermost level of water need be heated. This is true, but a householder cannot possibly know whether a small or large quantity of tank water needs heating since this depends, amongst other factors, on the cold water temperature and the temperature profile of the water in the tank. Thus, in winter when the cold water is at a much lower temperature than in the summer, a householder will naturally mix less cold water from the cold water supply with the hot water in the tank than he or she would do in summer. Therefore, the nominal volume of hot water available in the tank translates into different actual quantities of usable water depending on the cold water temperature. The prior art addresses the problem of estimating a volume of available water in the tank having a specified average temperature, but does not appear to take into consideration that what is of interest to the user is the actual volume of usable hot water, which may well be considerably more than the nominal hot water volume in the tank.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a hot water tank having multiple temperature sensors affixed thereto in a manner which addresses the drawbacks associated with hitherto approaches.

According to a first aspect of the invention there is provided a hot water tank containing an electrically conductive wall, a heating element and at least three temperature sensors disposed at respective heights of the tank for measuring local water temperature at respective points thereof, wherein each of the temperature sensors is an electrical conductor formed of a material different to that of the electrically conductive wall of the tank and which is bonded to the wall so as to form a thermocouple at a respective point of contact.

Water temperature is controlled by a control unit coupled to the thermocouples and responsive to respective signals produced thereby for estimating a quantity of hot water in the tank and providing an indication thereof to a user of the hot water tank. The control unit is also adapted to control a rate at which water in the tank is heated so that a required quantity of shower water, for example, at the desired water temperature (around 43°C) is available at a specified time.

The configuration according to the invention results in a very simple and low cost system requiring no changes in the structure of the water tank. Typically, the only change required is to solder five thermocouple wires to the external wall of the water tank and on the cold water input pipe or on the user's cold water cock. The thermocouples have no direct contact with the water, thus not being susceptible to corrosion or amortization and remaining reliable for the whole life of the water tank.

The control unit allows energy saving since water is heated only according to the user's needs. If operating properly there is no wastage caused by extra hot water that becomes cold after no usage. The expected life of the water tank is enhanced by the non-invasive manner in which the temperature sensors are affixed to the tank. The tank's longevity is further increased by reducing the quantity of

water that is heated unnecessarily thus reducing the accumulation of harmful lime sediment in the tank.

The control unit provides greater user convenience since the user has the certainty of a required quantity of shower water at any time (the quantity of shower water can be given either in liters or in terms of time for which shower water is required.) He can plan his day accordingly and can order a specific quantity of shower water at scheduled times. It also gives him an indication at any time during the day of the amount of shower water there is in either the hot water tank, or in a selected portion thereof. This can save him extra costs for unnecessarily heating wasted hot water. The system obviates the need for the existing boiler thermostat since the thermocouples measure the hot water temperature whilst the control unit controls the heating element.

The invention is applicable to all kinds and sizes of water tanks and boilers and not only for domestic boilers regardless of the kind of heating energy. The water tank according to the invention can form part of an integrated system for connection as a host to a central computer control for operating the control unit remotely.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Figs. 1a and 1b are schematic representations of a hot water tank according to different embodiments of the invention;

Fig. 2 is a block diagram showing functionally a control unit for controlling the water temperature in the hot water tank shown in Fig. 1; and

Figs. 3 to 5 are flow diagrams showing the principal operating steps carried out by the control unit shown functionally in Fig. 2.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 1a shows a first embodiment of a hot water tank 10 having a cold water inlet 11, a hot water outlet 12 and a heating element 13. The tank 10 has an outer wall 14 formed of iron to which there are soldered four constantin wires 15, 16, 17and 18 (constituting electrical conductors) at equally spaced intervals so as to provide a temperature profile through the tank. A fifth constantin wire 19 is soldered to a base 20 of the tank near the level of the cold water inlet 11 so as to measure the temperature of the cold water entering the tank. A fifth wire 21 formed of iron, being the same material as the tank wall, acts as a common wire which is soldered to the base 20 of the tank and all six wires are fed to an electronic control unit 22 that is responsive to the respective temperature differences across each of the thermocouple's ends for estimating a quantity of hot water in the tank and providing an indication thereof to a user thereof. Each of the constantin wires in conjunction with the common wire form respective thermocouples across which there is generated a voltage which is a function of the temperature difference across opposite ends of the wires. Thus, one junction of each thermocouple is formed between the constantin wires and the iron wall and base of the tank, whilst a remote junction of each thermocouple is formed between the constantin wires and the common wire remote from the tank. Thus, in order that the absolute temperature of the junction of each thermocouple at the hot water tank be determined, the temperature of the remote junction must first be measured and added to the temperature difference across opposite ends of the respective thermocouple. To this end, a thermistor 23 is provided near the common junction of the thermocouples which are themselves anchored in a terminal strip 31 outside the control unit 22 and connected thereto by respective wires 32 (constituting "auxiliary conductors") all formed of the same material, although not necessarily of identical material to the thermocouple wires. The location of the terminal strip 31 is not important: it can be provided anywhere between the water tank 10 and the control unit 22 and may, if desired, form an integral internal component of the water tank 10. Also shown in Fig. 1a for additional safety is an integral thermostat 23′ which is typically provided

as a standard feature for controlling the heating element 13, although normally it is rendered redundant by the control unit 22.

Fig. 1b shows a second embodiment similar in most respects to the first embodiment wherein like components are designated by identical reference numerals. The principal distinction between the two embodiments resides in the manner in which the thermocouples are bonded to the wall of the hot water tank 10. In Fig. 1b, an electrically conductive sleeve 33 having a base portion 34 is inserted lengthwise into the tank 10 and forms an inner wall of the tank, to whose inside surface the thermocouple wires are soldered. Here again, the inside surface of the sleeve 33 makes no contact with the water in the tank and the thermocouple junctions are thus protected against corrosion or amortization. The base portion 34 may also serve as the support for the heating element 13 and the thermostat 23′ so that the heating element 13, the thermostat 23′ as well as the sleeve 33 may be inserted into the tank 10 together.

Thus, within the context of the description and the appended claims, the term "wall" when used in association with the tank 10, envisages any barrier which spans the height of the tank and serves to contain water therein. In particular, this includes either the outer wall 14 of the tank as shown in Fig. 1a or an inner wall thereof as embodied by the sleeve 33 shown in Fig. 1b.

Fig. 2 shows functionally the principal components in the control unit 22. A thermistor 23 (constituting a temperature sensor) is provided outside the control unit 22 close to the terminal strip 31 of the thermocouple junction for measuring an ambient temperature in a vicinity thereof and producing a signal representative thereof. The thermocouple signals are directed from the terminal strip 31 to the control unit 22 and are fed to an amplifier 24 for amplifying the thermocouple voltages so as to produce respective amplified thermocouple signals. A look-up table 25 (constituting a converter) is coupled to the thermistor and is responsive to the signal produced thereby for converting the signal to an equivalent thermocouple signal corresponding to the ambient temperature. An adder 26 is coupled to the look-up table 25 and is adapted to be connected to each of the thermocouple wires

15, 16, 17, 18 and 19, via the terminal strip 31, for adding to respective amplified thermocouple signals produced thereby the equivalent thermocouple signal so as to produce a respective absolute thermocouple signal. A processor 28 coupled to the adder is responsive to each of the absolute thermocouple signals for producing a respective absolute temperature reading, which is displayed on a display 30 coupled to the processor 28.

The look-up table 25, the adder 26 and the processor 28 can be constituted by a suitably programmed microprocessor. The processor 28 can, if desired, be replaced by a second look-up table. Likewise, the look-up table 25 can be integrated within the processor 28 which may be programmed to calculate the equivalent thermocouple signal according to a pre–determined function. A keyboard 29 is coupled to the processor 28 and constitutes a temperature set device for manually setting a desired water temperature. As will be explained below, the keyboard 29 also serves as a quantity set device for manually setting data representative of a required quantity of water, and as a time set device for manually setting data representative of a specified time when the required quantity of hot water must be available. A display 30 is coupled to the processor 28 for displaying data entered by the user as well as water temperatures and quantities calculated by the control unit 22. The heating element 13 is energized via a heating control unit 35, which is responsively coupled to the processor 28 so as to be controlled thereby.

Referring to Fig. 3 the operation of the control unit 22 will now be described for determining the quantity Q of water available at a desired shower temperature. First, the voltage generated by the thermistor 23 is measured. This voltage value is translated through the look-up table 25 to another value called the equivalent value. The equivalent value is exactly the same value of an amplified voltage in the control unit 22 that should have been sourced by a virtual thermocouple whose one edge temperature is the same temperature as the thermistor environment and the other edge temperature is 0°C. This equivalent value is added arithmetically to the amplified voltage value of each one of the five thermocouples 15, 16, 17, 18 and 19. The resulting values are relative to the absolute temperatures (i.e. temperatures

The total estimated quantity Q of shower water is the sum of all Q_i (i = 1 to n), i.e.:

$$Q = \sum_{i=1}^{n}\left(\frac{1}{n}\cdot V\cdot\frac{\Delta T_i}{\Delta T_w}\right)$$

In the more general case where the profile thermocouples do not span the complete volume of the tank and/or are not equally spaced, the estimated quantity Q_i of shower water relevant to thermocouple i which represents $1/m_i^{\text{th}}$ of the boiler volume is given by:

$$Q_i = \frac{1}{m_i}\cdot V\cdot\frac{\Delta T_i}{\Delta T_w}$$

Where m_i is the fractional volume of the water tank served by the i^{th} thermocouple.

If desired, Q can be converted to a number of available showers for a specific user requiring a known average water consumption per shower, by dividing Q by the user's average water consumption per shower entered via the keyboard 28. Likewise, the time duration for which shower water at the required temperature is available may be calculated by dividing Q by a known average water flow rate in the shower. This can be measured either by means of a flow meter or experimentally. For example, the user can measure the time it takes to fill a bucket of known volume with shower water. The result can then be entered via the keyboard 29.

Alternatively, the user can enter a required number of showers and the control unit 22 may be adapted to multiply it by his given average water consumption per shower to derive the required shower water quantity N, or he can enter the required shower duration and the control unit 22 may be adapted to multiply it by the given average water flow rate in the shower to derive required shower water quantity N.

Referring to Fig. 5 the operation of the control unit 22 will now be described for automatically controlling the heating element so that the desired quantity Q of water at the desired shower temperature will be available at a specified time t.

The present water quantity Q for hot shower or very hot shower is first estimated according to the algorithm described above with reference to Fig. 4. If Q is greater than the user demand N then there is no need to heat the water tank, so the heating element 13 is disabled. If Q is less than N, then the heating element 13 must be energized for sufficient time that N should be ready at time t. The heating duration Δt is relative to the difference between N and Q and it is read from a look-up table or is computed according to a pre-programmed function. The heating is started at a time $(t - \Delta t)$. Whenever Q is greater than N the heating element is disabled.

It will be appreciated that modifications will be apparent to one of average skill in the art without departing from the scope of the invention as defined by the attached claims. For example, the principles of the invention are equally applicable to thermocouples formed of materials other than iron and constantin. Likewise, whilst in the preferred embodiment, four profile thermocouples are employed, it will be appreciated that this number may be varied if desired. The minimum number required is two plus one for measuring the cold water temperature, wherein one of the thermocouples is a reference thermocouple located at a height near a level of the cold water inlet or in the inlet cock of the hot water tank or at the user's cold water cock so as to provide a first signal indicative of the temperature of cold water.

It will also be noted that the invention encompasses controlling the heating element so as to provide either a specified volume of "shower water" or sufficient "shower water" for a specified time duration or for a specified number of showers at a specified time. The specified time can be entered directly via the keyboard 29 or via any other suitable interface. Alternatively, an incremental time interval can be entered starting from the current time can be entered, allowing the control unit 22 to compute the time at which hot water must be ready.

The desired hot water temperature may be entered in several ways. It can be entered via the keyboard; or a code can be entered indicative of the desired water temperature. For example, two settings may be provided: 40°C for a moderately hot shower and 45°C for a very hot shower, and the desired setting can be entered via the keyboard 29 or via any other suitable interface.

It will also be appreciated that the algorithms described for computing the available quantity Q of water at the desired temperature and for controlling the heating element are also applicable for hot water tanks and boilers employing conventional temperature sensors.

It will also be understood that the term "shower" is used by way of example. The principles of the invention are equally applicable to the controlled heating of a desired volume of tank water for any purpose, be it for a shower, bath, washing dishes or for any other purpose. Within the appended claims, the term "usable water" implies water at a desired temperature which is produced by mixing hot water already available in the tank with cold water obtained from the cold water supply so as to achieve a comfortable operating temperature for a required purpose.

It should also be noted that whilst in the preferred embodiments, the profile thermocouples are displaced equal intervals in the tank, this is not essential. The principles of the invention as described are equally applicable when spacing the thermocouples apart at different mutual distances and changing the formulae accordingly as explained above.

Finally, it will be appreciated that the control unit can be provided as a separate add-on unit for connecting to temperature sensors associated with a hot water tank.

In the method claims which follow, alphabetic characters used to designate claim steps are provided for convenience only and do not imply any particular order of performing the steps.

CLAIMS:

1. A hot water tank containing an electrically conductive wall, a heating element and at least three temperature sensors disposed at respective heights of the tank for measuring local water temperature at respective points thereof, wherein each of the temperature sensors is an electrical conductor formed of a material different to that of the electrically conductive wall of the tank and which is bonded to the wall so as to form a thermocouple at a respective point of contact.

2. The hot water tank according to Claim 1, wherein one of the thermocouples is a reference thermocouple located at a height near a level of the cold water inlet of the hot water tank so as to provide a first signal indicative of a temperature of cold water entering the tank, and remaining ones of said thermocouples are profile thermocouples displaced vertically along the wall of the tank so as to provide respective second signals indicative of a temperature profile of water in the tank.

3. The hot water tank according to Claim 1, wherein one of the thermocouples is a reference thermocouple located in association with a cold water supply so as to provide a first signal indicative of a temperature of cold water for mixing externally with water in the tank, and remaining ones of said thermocouples are profile thermocouples displaced vertically along the wall of the tank so as to provide respective second signals indicative of a temperature profile of water in the tank.

4. The hot water tank according to any one of the preceding claims, further including a control unit coupled to the thermocouples and responsive to respective signals produced thereby for estimating a quantity of water in the tank sufficient to produce a desired quantity of usable water and providing an indication thereof to a user.

5. The hot water tank according to Claim 4, wherein the control unit comprises:

a temperature sensor for measuring a temperature near respective ends of the thermocouples remote from the hot water tank and producing a signal representative thereof,

a converter coupled to the temperature sensor and responsive to said signal for converting said signal to an equivalent thermocouple signal corresponding to the temperature in said respective ends of the thermocouples,

an adder coupled to the converter and adapted to be connected to each of the thermocouples for adding to respective thermocouple signals the equivalent thermocouple signal so as to produce a respective absolute thermocouple signal,

a processor coupled to the adder and responsive to each of the absolute thermocouple signals for producing a respective absolute temperature reading, and

a display coupled to the processor for displaying said absolute temperature readings.

6. The hot water tank according to Claim 5, wherein;

the respective ends of the thermocouples remote from the hot water tank are anchored between the water tank and the control unit, and

the thermocouple signals are fed to the control unit via auxiliary conductors formed of identical material, which is not necessarily identical to the material of the thermocouple wires.

7. The hot water tank according to Claim 5, wherein the converter is a look-up table.

8. The hot water tank according to Claim 5, wherein the converter is a computer programmed to calculate the equivalent thermocouple signal according to a predetermined function.

9. The hot water tank according to any one of Claims 4 to 8, wherein the control unit further includes a temperature set device for manually setting a desired usable water temperature, and is responsive thereto for estimating an available quantity of water in the tank sufficient to produce a desired quantity of usable water having the desired water temperature.

10. The hot water tank according to Claim 9, wherein the converter, the adder and the processor are constituted by a suitably programmed microprocessor.

11. The hot water tank according to Claim 10 when dependent on Claim 3, wherein the control unit is adapted to:

(a) compute a difference ΔT_w between the desired usable water temperature and the cold water temperature, and

for each of the profile thermocouples:

(b) compute a temperature difference ΔT_i between the water temperature measured by the respective thermocouple and the cold water temperature,

(c) compute a volumetric fraction of usable water in the tank having an average temperature equal to the desired temperature as a function of:

$$\frac{1}{m_i} \cdot V \cdot \frac{\Delta T_i}{\Delta T_w}$$

where $1/m_i$ is a fraction of the volume V of the hot water tank served by the i^{th} thermocouple,

(d) accumulating each of the volumetric fractions of usable water in the tank so as to provide an average accumulated volume of usable water in the tank having the desired temperature, and

(e) displaying the average accumulated volume of usable water in the tank having the desired temperature.

12. The hot water tank according to Claim 9, wherein the control unit is adapted to control a rate at which water in the tank is heated so that a required quantity of water at said desired usable water temperature is available at a specified time.

13. The hot water tank according to Claim 12, wherein the control unit includes:

a quantity set device for manually setting data representative of said required quantity of usable water, and

a time set device for manually setting data representative of said specified time.

14. The hot water tank according to Claim 13, wherein said data is a required volume of usable water.

15. The hot water tank according to Claim 13, wherein said data is a required number of showers.

16. The hot water tank according to Claim 13, wherein said data is a required shower duration.

17. The hot water tank according to Claim 13, wherein the control unit is adapted to:

(a) estimate according to Claim 11 a present quantity of usable water in the tank whose temperature is equal to the desired temperature,

(b) if the present quantity of shower water in the tank estimated in step **(a)** exceeds the required quantity of usable water, disabling the heating element, otherwise:

i) determining a time duration Δt for which the water must be heated in order to bring it up to the desired temperature,

ii) enabling the heating element at a start time equal to Δt prior to the specified time, and

(c) repeating steps **(a)** and **(b)**.

18. The hot water tank according to Claim 17, wherein the control unit includes a time duration look-up table for determining the time duration Δt in step **(c)**.

19. The hot water tank according to any one of the preceding claims, wherein the material from which the electrical conductors are formed is constantin.

20. The hot water tank according to any one of the preceding claims, wherein the electrically conductive wall is an outer wall of the tank.

21. The hot water tank according to any one of the Claims 1 to 19, wherein the electrically conductive wall is an inside surface of a sleeve inserted lengthwise into the tank .

22. A method for estimating an available quantity of usable water having a desired water temperature from a hot water tank fed by cold water heated by a controllable heating element, the tank having a plurality of spaced apart profile temperature sensors for measuring a temperature profile through the tank and a cold water sensor for determining a temperature of cold water for mixing externally with water in the tank so as to produce said usable water, the method comprising the steps of:

(a) computing a difference ΔT_w between the desired usable water temperature and the cold water temperature, and

for each of the profile temperature sensors:

(b) computing a temperature difference ΔT_i between the water temperature measured by the respective temperature sensor and the cold water temperature,

(c) computing a volumetric fraction of usable water in the tank having an average temperature equal to the desired temperature as a function of:

$$\frac{1}{m_i} \cdot V \cdot \frac{\Delta T_i}{\Delta T_w}$$

where $1/m_i$ is a fraction of the volume V of the hot water tank served by the i^{th} thermocouple, and

(d) accumulating each of the volumetric fractions of usable water in the tank so as to provide an average accumulated volume of usable water in the tank having the desired temperature.

23. The method according to Claim 20 for controlling the heating element based on the estimated available quantity of usable water having the desired water temperature, further comprising the steps of:

(e) entering data representative of a specified time at which the required usable water is required,

(f) if the present quantity of usable water in the tank estimated in step **(a)** exceeds the required quantity of usable water, disabling the heating element, otherwise:

(g) determining a time duration Δt for which the water must be heated in order to bring it up to sufficient temperature so that if necessary, when mixed with cold water, the usable water is of the desired temperature,

(h) enabling the heating element at a start time equal to Δt prior to the specified time represented by the data specified in **(e)**, and

(i) repeating steps **(b)** to **(d)** and **(f)** to **(h)**.

24. A control unit for a hot water tank containing an electrically conductive wall, a heating element and at least three thermocouples disposed at respective heights of the tank for measuring local water temperature at respective points thereof, the control unit comprising:

a temperature sensor for measuring a temperature near respective ends of the thermocouples remote from the hot water tank and producing a signal representative thereof,

a converter coupled to the temperature sensor and responsive to said signal for converting said signal to an equivalent thermocouple signal corresponding to the temperature in said respective ends of the thermocouples,

an adder coupled to the converter and adapted to be connected to each of the thermocouples for adding to respective thermocouple signals the equivalent thermocouple signal so as to produce a respective absolute thermocouple signal,

a processor coupled to the adder and responsive to each of the absolute thermocouple signals for producing a respective absolute temperature reading, and

a display coupled to the processor for displaying said absolute temperature readings.

25. The control unit according to Claim 24, wherein the converter is a look-up table.

26. The control unit according to Claim 24, wherein the converter is a computer programmed to calculate the equivalent thermocouple signal according to a predetermined function.

27. The control unit according to any one of Claims 24 to 26, further including a temperature set device for manually setting a desired usable water temperature, and being responsive thereto for estimating an available quantity of water in the tank sufficient to produce a desired quantity of usable water having the desired water temperature.

28. The control unit according to Claim 27, wherein the converter, the adder and the processor are constituted by a suitably programmed microprocessor.

29. The control unit according to any one of Claims 24 to 28 wherein one of the thermocouples is a reference thermocouple located in association with a cold water supply so as to provide a first signal indicative of a temperature of cold water for mixing externally with water in the tank, and remaining ones of said thermocouples are profile thermocouples displaced vertically along the wall of the tank so as to provide respective second signals indicative of a temperature profile of water in the tank, the control unit being adapted to:

(a) compute a difference ΔT_w between the desired usable water temperature and the cold water temperature, and

for each of the profile thermocouples:

(b) compute a temperature difference ΔT_i between the water temperature measured by the respective thermocouple and the cold water temperature,

(c) compute a volumetric fraction of usable water in the tank having an average temperature equal to the desired temperature as a function of:

$$\frac{1}{m_i} \cdot V \cdot \frac{\Delta T_i}{\Delta T_w}$$

where $1/m_i$ is a fraction of the volume V of the hot water tank served by the i^{th} thermocouple,

(d) accumulating each of the volumetric fractions of usable water in the tank so as to provide an average accumulated volume of usable water in the tank having the desired temperature, and

(e) displaying the average accumulated volume of usable water in the tank having the desired temperature.

30. The control unit according to Claim 29, being adapted to control a rate at which water in the tank is heated so that a required quantity of water at said desired usable water temperature is available at a specified time.

31. The control unit according to Claim 30, including:

a quantity set device for manually setting data representative of said required quantity of usable water, and

a time set device for manually setting data representative of said specified time.

32. The control unit according to Claim 31, wherein said data is a required volume of usable water.

33. The control unit according to Claim 31, wherein said data is a required number of showers.

34. The control unit according to Claim 31, wherein said data is a required shower duration.

35. The control unit according to Claim 31, being adapted to:

(a) estimate according to Claim 11 a present quantity of usable water in the tank whose temperature is equal to the desired temperature,

(b) if the present quantity of shower water in the tank estimated in step **(a)** exceeds the required quantity of usable water, disabling the heating element, otherwise:

i) determining a time duration Δt for which the water must be heated in order to bring it up to the desired temperature,

ii) enabling the heating element at a start time equal to Δt prior to the specified time, and

(c) repeating steps **(a)** and **(b)**.

36. The control unit according to Claim 35, including a time duration look-up table for determining the time duration Δt in step **(c)**.

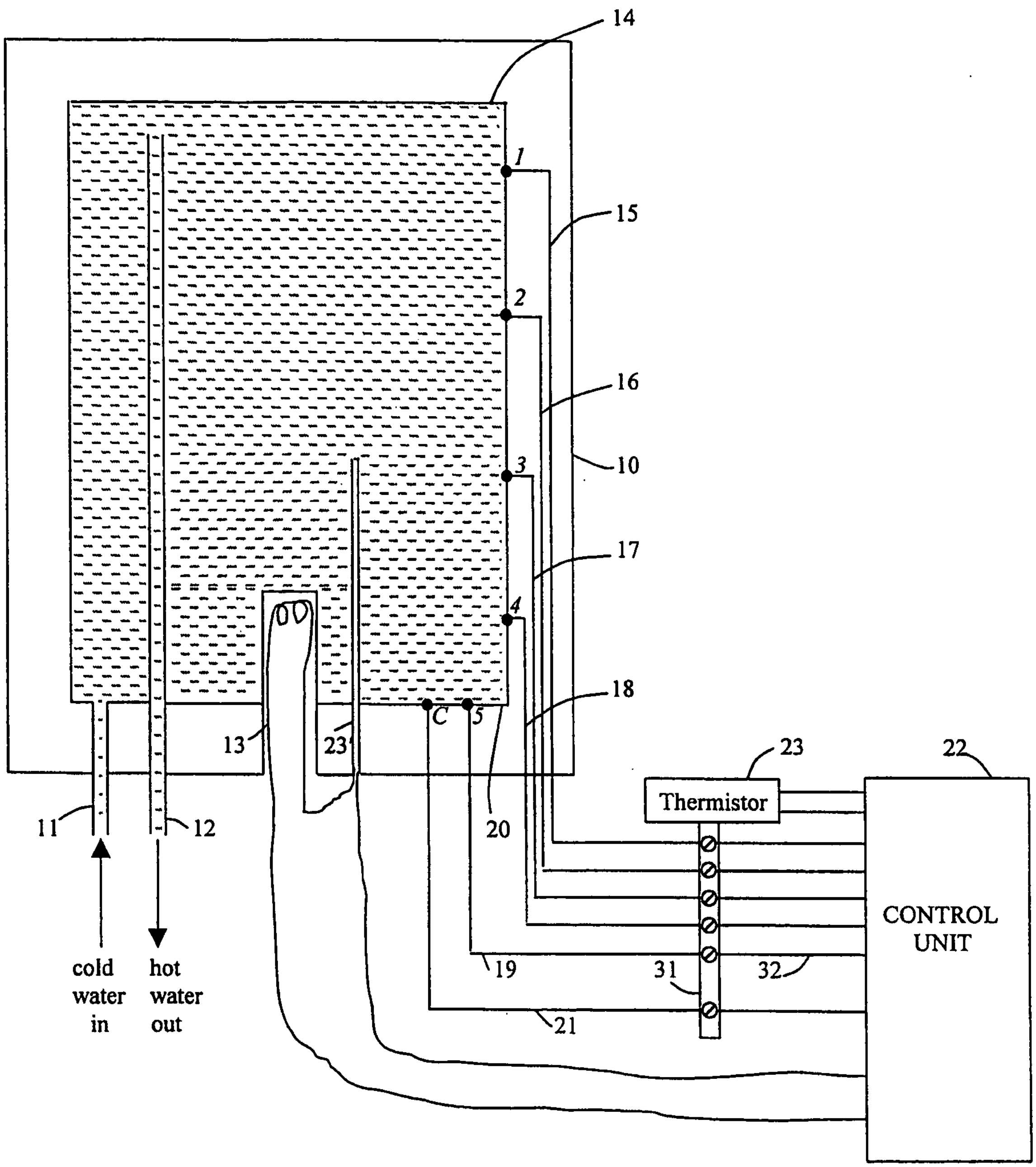
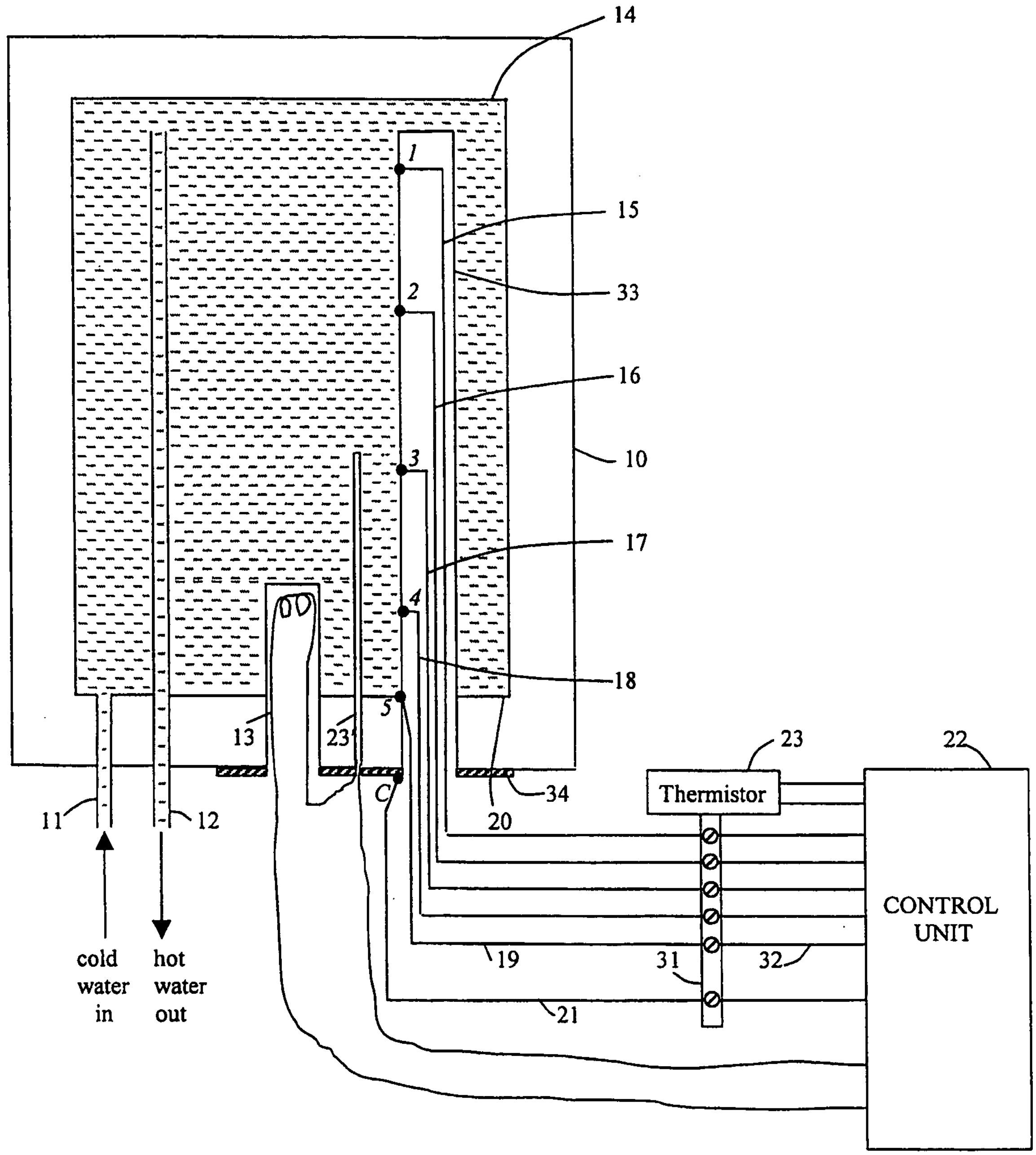

14
1
15
2
16
3
10
17
4
18
C
5
13
23
20
11
12
23
22
Thermistor
CONTROL UNIT
cold water in
hot water out
19
31
32
21

FIG. 1a


14
1
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18
5
13
23
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23
Thermistor
C
34
20
11
12
CONTROL UNIT
19
31
32
21
cold water in
hot water out

FIG. 1b

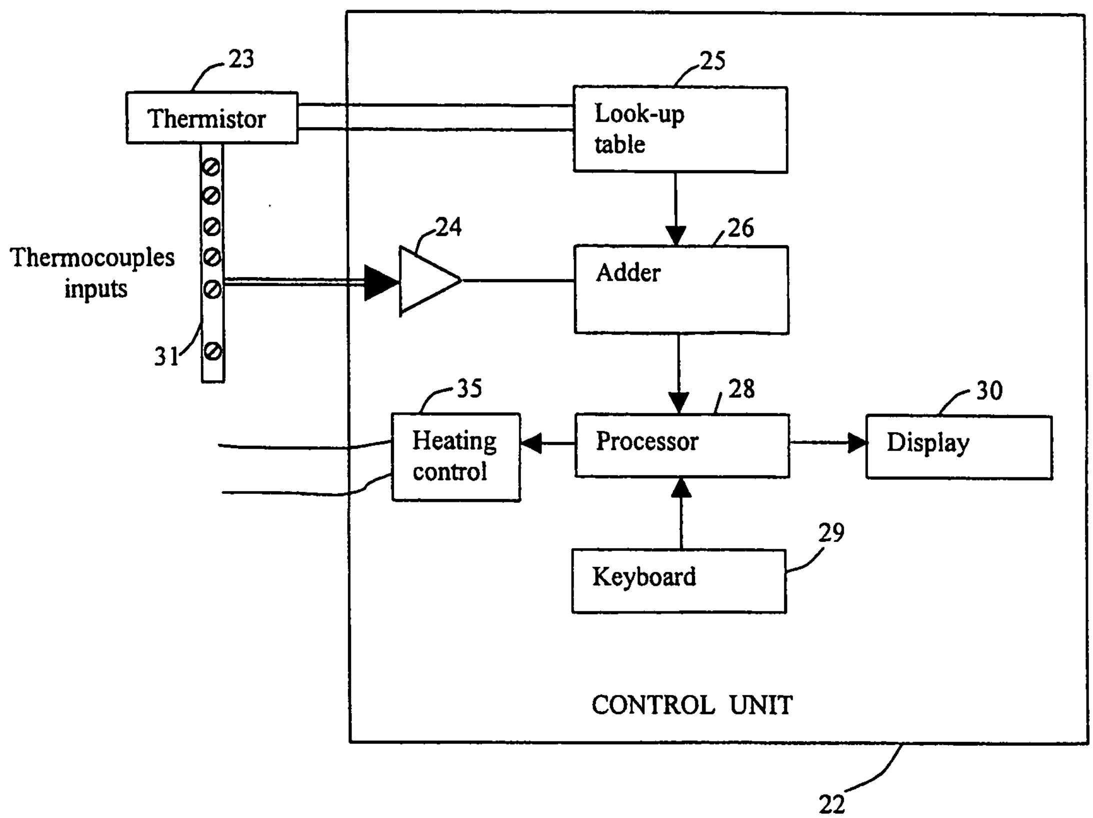
23
Thermistor
25
Look-up
table
24
26
Adder
Thermocouples
inputs
31
35
Heating
control
28
Processor
30
Display
29
Keyboard
CONTROL UNIT
22

FIG. 2

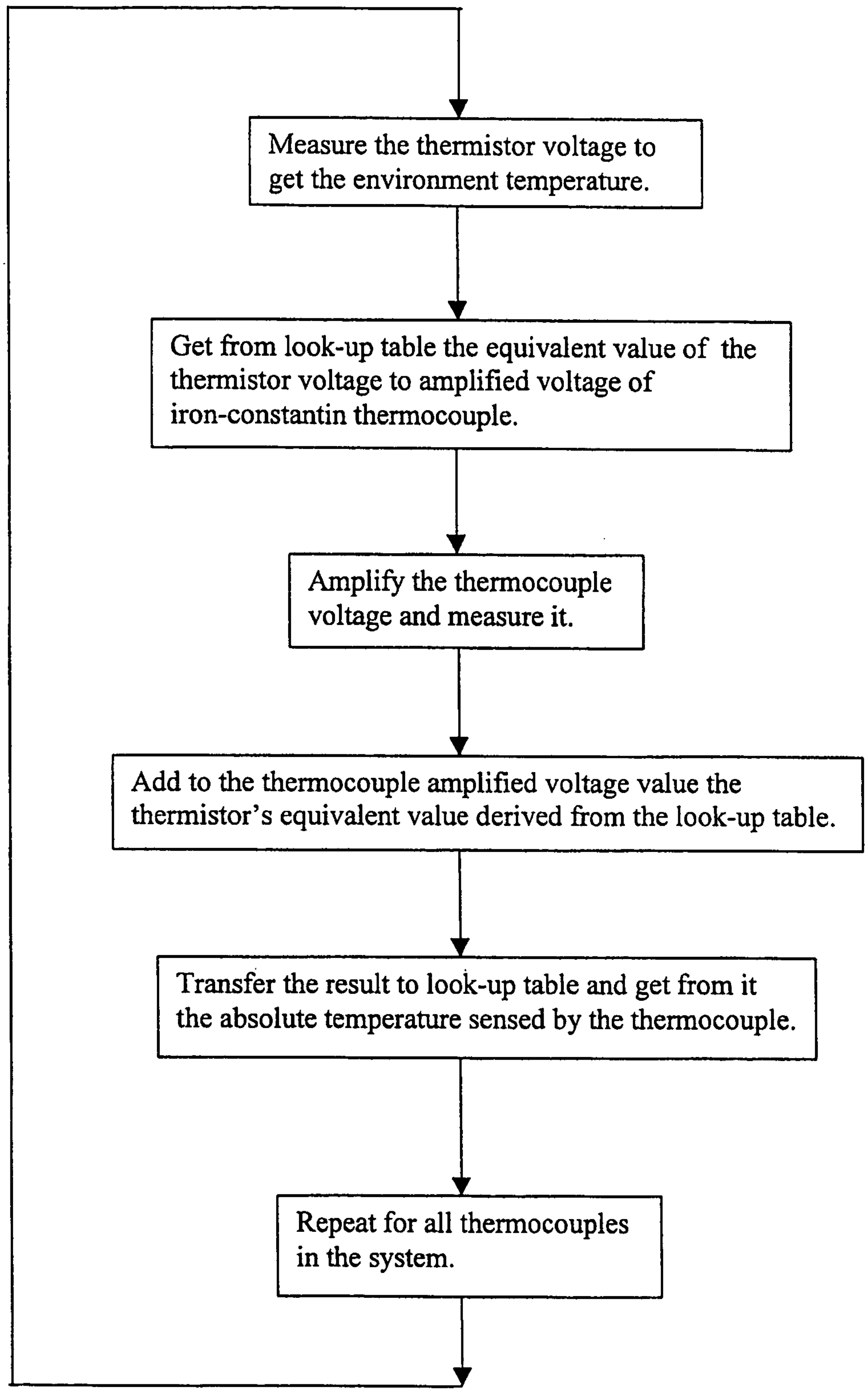
Measure the thermistor voltage to get the environment temperature.
Get from look-up table the equivalent value of the thermistor voltage to amplified voltage of iron-constantin thermocouple.
Amplify the thermocouple voltage and measure it.
Add to the thermocouple amplified voltage value the thermistor's equivalent value derived from the look-up table.
Transfer the result to look-up table and get from it the absolute temperature sensed by the thermocouple.
Repeat for all thermocouples in the system.

FIG. 3

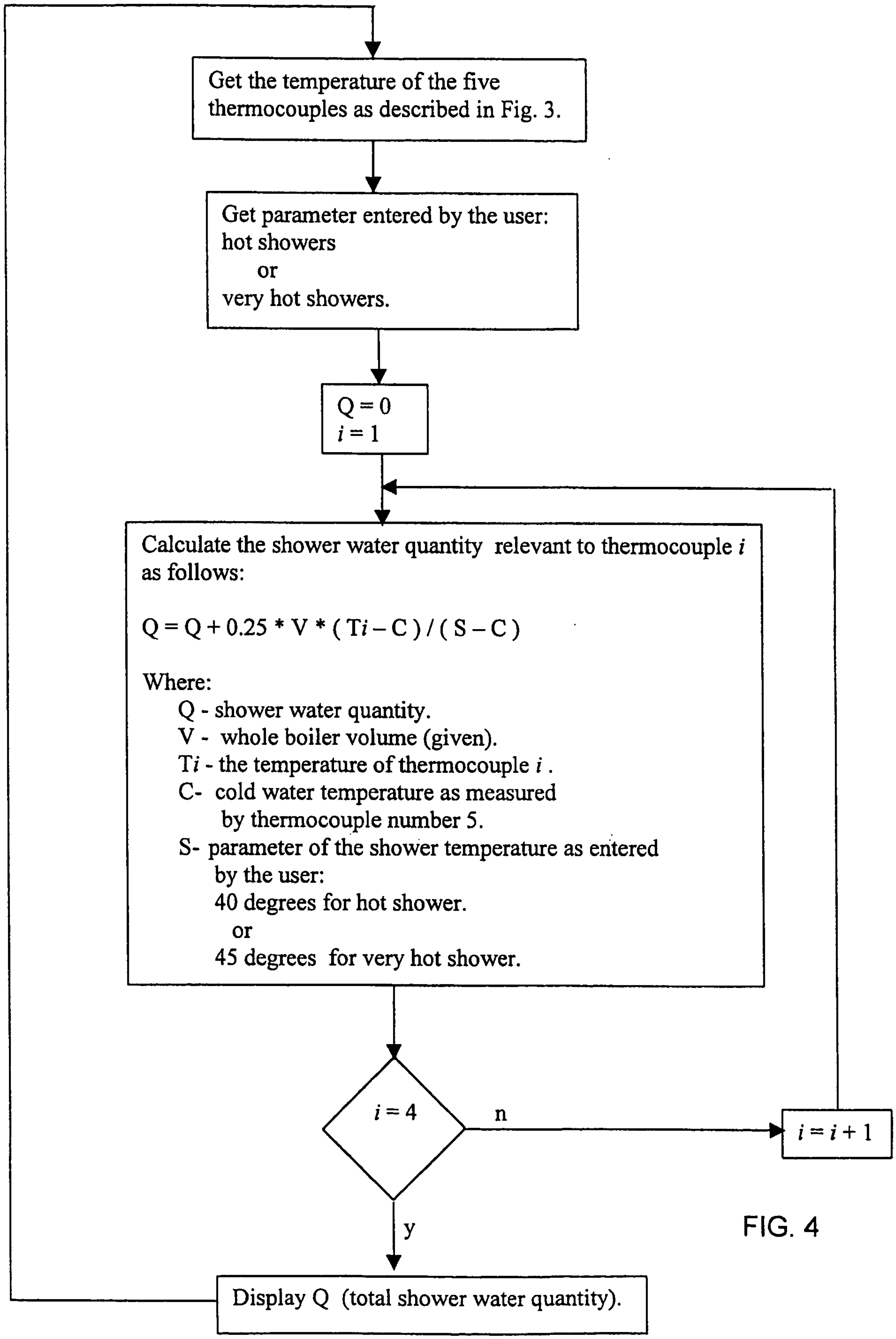
Get the temperature of the five thermocouples as described in Fig. 3.
Get parameter entered by the user: hot showers or very hot showers.
Q = 0
i = 1
Calculate the shower water quantity relevant to thermocouple i as follows:
Q = Q + 0.25 * V * (Ti – C) / (S – C)
Where:
Q - shower water quantity.
V - whole boiler volume (given).
Ti - the temperature of thermocouple i .
C- cold water temperature as measured by thermocouple number 5.
S- parameter of the shower temperature as entered by the user:
40 degrees for hot shower.
or
45 degrees for very hot shower.
i = 4
n
i = i + 1
y
Display Q (total shower water quantity).

FIG. 4

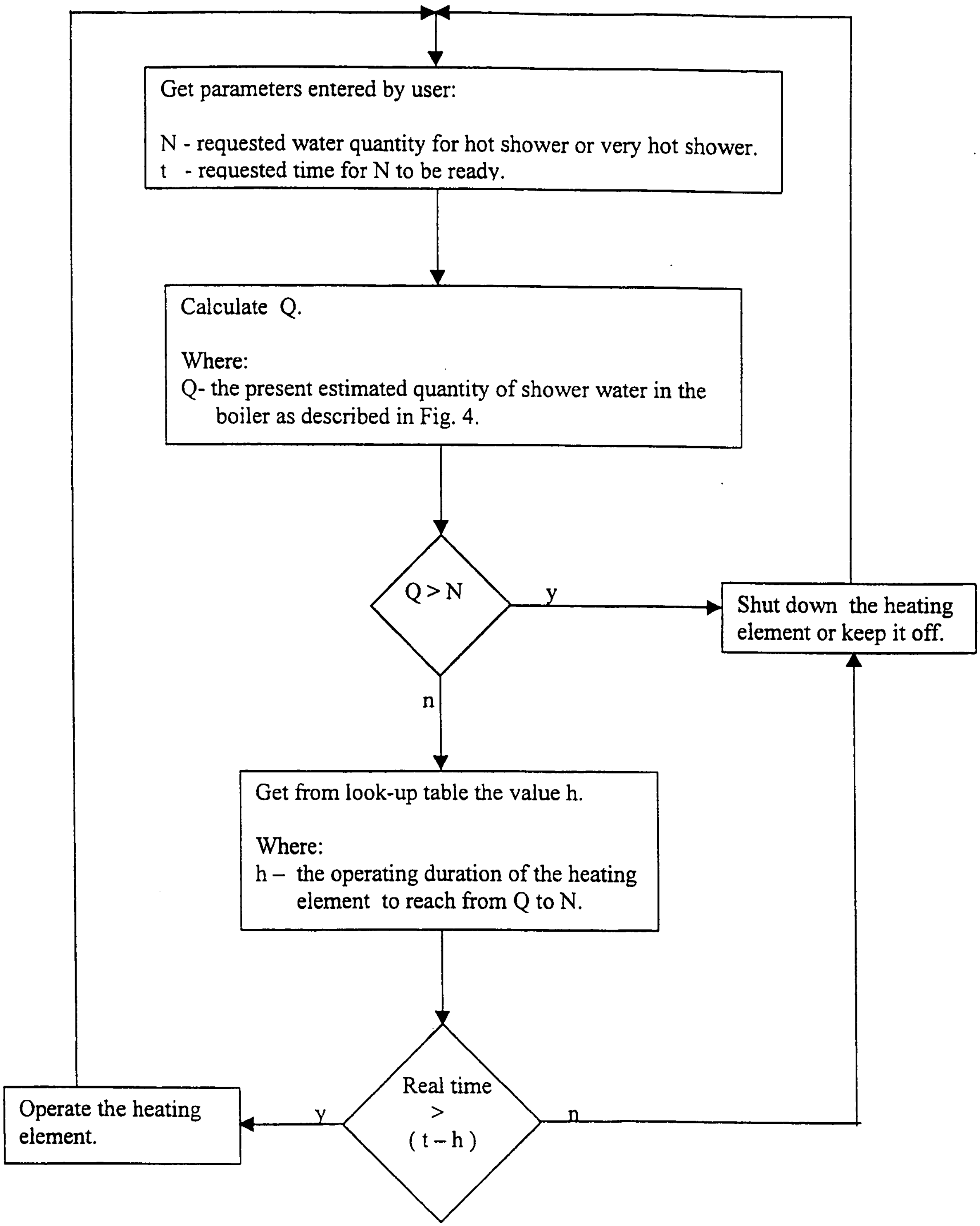
Get parameters entered by user:
N - requested water quantity for hot shower or very hot shower.
t - requested time for N to be ready.
Calculate Q.
Where:
Q- the present estimated quantity of shower water in the boiler as described in Fig. 4.
Q > N
y
Shut down the heating element or keep it off.
n
Get from look-up table the value h.
Where:
h – the operating duration of the heating element to reach from Q to N.
Real time > (t – h)
y
n
Operate the heating element.

FIG. 5

International Application No
PCT/IL 00/00159

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F24D19/10 F24H9/20 G01K7/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F24D F24H G01K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 125 169 A (HYDROCARBON RESEARCH INC) 29 February 1984 (1984-02-29) abstract	1
X	EP 0 756 160 A (HERAEUS SENSOR GMBH) 29 January 1997 (1997-01-29) abstract	1
A	DE 196 02 973 A (SCHNEIDER ROLF) 31 July 1997 (1997-07-31) abstract	1,11,22
A	GB 2 132 791 A (BAKER COLIN;STEIN DR JOHN) 11 July 1984 (1984-07-11) abstract	1,11,22
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 June 2000	16/06/2000
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Van Gestel, H

Intern ıal Application No
PCT/IL 00/00159

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 536 109 A (AUSTRIA EMAIL EHT AG) 7 April 1993 (1993-04-07) abstract -----	1,11,22

1

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EP 0756160 A	29-01-1997	DE 19526975 A	30-01-1997
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